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THE PROSPECT OF AERIAL NAVIGATION.

BY SIMON NEWCOMB, LL.D.

SOME twenty-five years ago, when the building of our new Navy was just commencing, the writer was conversing with a friend whose official duty it was to provide for the armament of the new ships. I remarked that there was one point connected with ordnance about which physical science might have something to suggest. This indicated the lines along which efforts to improve the gun could be most hopefully directed. The longer the gun the more advantageous it was in theory, when the relations between muzzle-velocity, explosive power and weight of gun were worked out. The Chief replied that all experience up to that time had shown that nothing was to be gained by increasing the length of the gun. I admitted that this might well be the result so far as practical experience had yet gone, but that, if so, it only showed that the art of making powder burn in the right way had not been perfected, and that when this was done the principle of lengthening the gun would come into play. I strongly suspect that he looked upon this view as practical men commonly do upon the results of purely mathematical theory; yet it was not long before even practical experience succeeded in replacing the old-fashioned "beer-bottle" of the Civil War with the type of gun, forty feet long, more or less, which now projects from the turrets of our battle-ships.

It is now proposed to inquire whether abstract physical science may not have something to say about the methods of aërial navigation to which recent successes, both in ballooning and flying, have given so large a space in the public mind. If it can do nothing more it may at least give us some hints as to the direction which improvement is to take, if such navigation is ever to be a commercial success.

Every one interested in the subject knows that the vehicles to be used in navigating the air are of two distinct types. One of these is based on the balloon. Its essential feature is that the vehicle must be as a whole lighter than air, so as to be supported in the air by its own buoyancy. This idea is embodied in the dirigible balloon. The other type is that of the flying-machine heavier than air. Several forms of flyer have been proposed, but they all have the common feature of being supported by a rapid movement through the air, on the principle on which a bird flies or soars by means of its wings. The best known and, I believe, the only one that has heretofore been tried with any approach to success, is the aëroplane, which is practically a soaring machine, and which both the Wright Brothers of Ohio and Farman of Paris are engaged in perfecting. The idea of flying like an eagle is so much more captivating than that of ballooning that, for the moment, popular interest is centred upon the vehicle which seems to promise that flying is feasible. The success attained by the dirigible balloon has helped to diffuse the idea that it may be replaced by the aëroplane. Our present purpose is to inquire whether this inference is well founded.

So far as results are concerned, the dirigible balloon is the form which seems to have reached the best measure of success. At least, that is what may be inferred from the flights that were made last autumn in the great competitive trial from St. Louis, which were hundreds of times longer than the Farman or Wright flyer has ever gone. At the same time, it must be confessed that a long step is still to be taken before the dirigible balloon can compete with the railroad in the cheap transportation of passengers and mails, and that the prospect of commercial success is still far in the future. Let us, then, return to the flyer, and inquire whether there is any sound reason to base a hope for its success upon results reached by the dirigible balloon. The fact is that the two types of machine are as radically different as a steamship and locomotive in the principle on which they operate. To see in what the difference consists, let us study the principles at play in the great ocean steamship. The success both of this and of the dirigible balloon grows out of a physical principle, easy of comprehension by any one acquainted with so much of geometry and physics as is taught in the High School: indeed, one which can perhaps be well grasped by any reader who has a common-school education. I shall call it the principle of the square and cube. There is no need of putting it into mathematical form; this can be as well done by an illustration from the history of ship-building during the last half century, as by any mathematical statement.

Fifty years ago, a great ocean steamship was about 300 feet long and 35 feet beam, with a tonnage of 3,000 to 4,000, and engines of perhaps 2,000 horse-power. These sufficed to drive the ship at a speed of ten or twelve knots. At that time the builders of such ships might well have doubted whether any of much larger type would prove a commercial success. The warning example of the "Great Eastern," which, immense though it was, had proved a total failure, was fresh in the minds of every shipper. But this experience need not have discouraged a physicist, who would have claimed that the failure was due to some defect in the model of the ship, or in her method of propulsion. Taking the case of a ship propelled by a screw, which had already been proved superior to the paddle-wheel, he might have made this little calculation. Build a ship twice the size of the present one in every dimension; instead of her length being 300 feet, let it be 600, and let her be twice as broad and twice as deep. The cubical dimensions of the proposed ship will then be eight times those of the present one; she will carry eight times the freight, and have room for eight times as many passengers. If her plates are twice as thick, her weight will also be multiplied by eight, but this will probably be unnecessary, as nearly the same thickness of plate will answer for the larger as for the smaller model. You can, if you choose, put in engines of eight times the power without taking up more than their proportional space in the present ship. So far nothing is gained. But mark! The surface which she exposes to the water and the storm is only increased four times. Therefore, if you are satisfied with the speed of the ship you now have, her engines need have only four times their present power, and will therefore fill only half the proportional space in the proposed ship. And you will certainly not need more than four times the number of men to run her. You will, therefore, be able to carry freight at little more than half the cost per ton without lessening the speed. If you aim also at high speed, you can secure it by increasing the power of your engines, and it will then be a purely economic question what combination of power and speed will best serve your purpose. You have a range of choice from engines of four times their present power, to those of eight times; the first involves a saving of one-half in the cost of running; the other an increase of speed at the same cost that is now incurred. In a word, physical science shows that the larger you build your ship the more economical she is in the ratio of efficiency to cost of running. The only limits to size are those set by such conditions as the depth of water in harbors and the amount of freight or the number of passengers that can be advantageously carried on a single ship. We thus see that the ocean Leviathan of our time has been developed in strict accord with the traditional laws of geometry and mechanics.

The same principle applies to the dirigible balloon, or any other form of ship that is to float in the air. Double its linear dimensions, make its walls twice as thick if you choose, and you will have eight times the cubical space, and eight times the buoyant power. But you will require only four times the propelling power to drive her through the air with a given speed, and therefore only four times the horse-power in her engines. There is no difficulty in conceiving an ideal ship which would be a commercial success were it not for the practical difficulties in the way of realization. I have a mental image of a structure much larger than any ship that navigates the ocean, say three or four hundred feet in diameter, nearly the same in height, a thousand feet or more in length, built out of rolled sheet steel one-twentieth or one-thirtieth of an inch thick,—inflated with hydrogen gas. Of course, the sheets must be perfectly gas-proof; the slightest crevice in them would be fatal. If the conception in which we are indulging were purely ideal, we should have a tube twenty or thirty feet in diameter, running centrally through the whole length of the ship, which would contain engines, passengers and freight. But we do not propose to indulge in a dream that, even if realized, might not prove a success. The practical difficulty with the inner tube would be that of having it firmly connected with the outer steel skin, and at the same time connecting the whole fabric so that, when the ship rose in the air, the skin would have the necessary flexibility to accommodate itself to the varying pressure and temperature of the air. Passengers, freight and engines must, therefore, be suspended from the ship in much the same way as in the present dirigible balloon. Taking the engines and the metal of which they are made just as we now have them, there is little doubt that such a ship as I have described could be driven at a speed ranging from fifty to one hundred miles an hour, and could visit any part of the world not too high above sea-level, including both the poles.

I must beg the reader not to misunderstand this claim in favor of the theoretical possibility of an immense aërial ship. We must distinguish between obstacles to progress placed in our way by nature itself, which can be overcome only by the discovery of some hitherto unknown law of nature, or of some new metal or alloy; and obstacles which arise only from the limitation of our power to solve great mechanical and engineering problems. We are only picturing what results might be reached could we but overcome all practical difficulties. I do not claim that men can ever build this ideal ship. The engineering and constructing difficulties are beyond any ever encountered, the problem of inflation seems nearly insuperable, and even the gas would cost a great fortune. We could not rely upon so vast a surface being soldered without a single flaw. An immense structure would be required to protect so huge and yet feathery a mass from the wind; but I do say that if we could overcome these practical difficulties, so as to actually build and inflate the ship, we should have a successful aërial ship. And I do not believe we shall ever have a commercially successful one until we do. With this claim I turn the subject over to engineers, constructors and others to be handled in their own way.

Now, our principle of the square and cube applies to the aëroplane, and to every form of flying-machine pure and simple; but it is reversed in the application. With every increase in the size of the machine the weight increases as the cube of the linear dimension, always supposing that the model remains the same. Possibly it might not always be necessary to increase the thickness in the same proportion as the length and breadth, but in every case the weight would necessarily increase in a higher ratio than the square of the length or breadth. But, the sustaining power being proportional to the surface, or to the spread of wing, whenever we increase the size of the flyer or of the aëroplane, the sustaining power diminishes relatively to the size. We see this exemplified in the limitations put upon the size and agility of flying animals; the smaller they are, the more easily they fly. There is a certain weight, which probably is less than the weight of a man, which no bird can ever exceed.

The principle we have applied does not of course set any precise limit to the weight which a flying-machine may possibly be made to carry. It only says that the advantage in increasing the size and weight continually diminishes. A very small machine, say one less in size than a humming-bird, would carry only the weight of a humming-bird. At the other extreme there is a size,—we cannot say exactly what, but not many yards in length,—beyond which no machine can be made to carry more than its own weight. There is a certain intermediate size where the maximum weight, perhaps that of one or more men, can be carried; and this size can never be exceeded with advantage.

This limitation upon size applies only to the case when we enlarge the machine in all its dimensions—in height as well as in length or breadth. But it has been pointed out by Bell that a general enlargement on one and the same model may be avoided by using a combination of small machines instead of a single large one. This is true to a certain extent; we might almost say that there is no limit to the possible superficial dimensions of a combination of aëroplanes. If we should arrange four separate Farman flyers in two pairs, side by side and end to end, they might possibly perform as well in combination as each would perform separately. The one disadvantage would be that the forward ones might "take the wind" from those behind it. But for this drawback there would be a positive, though small, advantage if they were placed end to end so as to form a train of any length. But, if we attempt to gain an advantage by the substitution of a single large machine for a combination of small ones, drawbacks will at once be encountered which will speedily become insuperable.

In describing the two types of aërial vehicle as quite distinct, it is not implied that no combination of the principles of the two is possible, which may result in a combined machine more advantageous than either. In the case of the dirigible balloon, the difficulties are purely those of construction. In the aëroplane they are inherent in the very theory of the action; but it is quite possible that an attachment to the airship similar in principle to the bilge keel of the ocean steamship may afford the best combination. The question thus raised is one for the inventor, to the solution of which the mathematical physicist may be able to contribute after the inventor has worked out a plan. The function of the physicist, therefore, seems worthy of consideration.

In reading, as we all do, of the efforts of inventors during the last twenty years to construct a practicable flying-machine, it is difficult to avoid the conclusion that they have overlooked the aid that might be afforded them by physical science in enabling them to predict, in advance of costly experiments, whether a given plan would prove successful when tried. An example of what should be done is afforded in the regular work of designing any great seagoing ship. No marine constructor would think of starting with the building of a ship on any other than well-known models until he had made a careful computation of her weight, buoyancy and stability. If he neglected to do this, the result might be that the ship would capsize immediately on being launched. A recent deplorable experience reported from Italy shows that the computation should be made even if the model is the usual one. The calculations in question are, of course, long and intricate, yet they are necessary; and any constructor dispensing with them should be deemed unworthy of his profession.

Now, the performance of any flying-machine of which an exact design is made, showing the dimensions, material and weight of every part, the power of the engines, and the size and form of the propellers, admits of being computed in advance through the known results of experiments on the resistance of air. It is true that the computation cannot be made with the same certainty and precision as in the case of a ship, because the data themselves are not so certain, and there may be difficulty in accurately determining the speed. The computation is also more intricate and involves a wider range of considerations. Yet it is fully within the power of any expert in mathematical physics to make it, and the labor involved in doing so, intricate though the problem is, would be much less than in the case of a great ship. The cost also would be only a small fraction of the money and time spent in making the machine. The laws of force and motion are paramount in the working of all machinery, and the successful man is not the one who disregards them, but he who understands them so well that he is enabled to apply them so as to secure success and avoid failure. But his understanding must be complete—a condition which, so far as we can judge from current utterances, is not appreciated by all the inventors of flying-machines who are coming forward. The order of progress is a complete study and appreciation of the abstract principles of force and motion. With these, the conditions can be studied and calculated by a mathematical physicist, and by no one else. When the mathematician has done his work, and made clear what difficulties there are and what conditions may be satisfied, then the inventor may devise some way of avoiding them. But to attempt to avoid them before he appreciates what they are—to go on before he knows whether he will or will not succeed—is a policy certain to result in failure. To the optimistic public, it might seem that the success of Farman in constructing a flying-machine which will actually carry a man settles the entire question, and shows that no further aid from science is necessary. But it would be contrary to the common course of human experience to suppose that Farman has reached the best and only form of aërial vehicle. The experiments of Graham Bell with kites show that there may be a great number of combinations, the possibilities of which have not yet been worked out, and which may lead to a better solution than even that reached by Farman. Such being the case, it is requisite that progress be as rapid as possible. The inventor, the physicist and the experimenter should work in combination, the one designing his plans, the other making the computations necessary to know whether it is possible that they can work, and the experimenter—who, of course, may be the inventor himself—making such trials as may be necessary to determine points on which the physicist is in doubt.

The question of greatest public interest is the practical one whether men now living may reasonably hope to see aërial navigation prosecuted in such a way as to be commercially successful, or to afford the public, or any part of it, a method of transporting passengers or things from place to place with more celerity and economy than under our present system. I conceive that, while science cannot answer this question categorically, it will enable us to state with a fair approach to certainty the conditions of success. The airship proper, or dirigible balloon, can be a commercial success only when expanded to such dimensions that thin metal sheets can take the place of a textile fabric in the structure. I say this on the supposition that no such fabric can be made perfectly gas-proof, so that when once inflated it can be run for months and years without any new supply of gas. If this supposition is incorrect, if a textile fabric can be made to hold the gas indefinitely, then success may be reached on the present system. As has already been pointed out, the obstacles in the way of success are those of construction and engineering rather than those of natural law.

It would seem that, at the present time, the public is more hopeful of the flying-machine than of the dirigible balloon. The idea that because such a machine has at last been constructed, which will carry a man through the air, there is no limit to progress, is a natural one. But to judge of possibilities, we must advert to the distinction already pointed out between obstacles interposed by nature, which cannot be surmounted by any invention, and those which we may hope to overcome by possible mechanical appliances. The mathematical relations between speed, sustaining power, strength of material, efficiency of engine, and other elements of success are fixed and determinate, and cannot be changed except by new scientific discoveries, quite outside the power of the inventor to make. That the gravitation of matter can in any way be annulled seems out of the question. Should any combination of metals or other substances be discovered of many times the stiffness and tensile strength of the fabrics and alloys with which we are now acquainted, then might one element of success be at our command. But, with the metals that we actually have, there is a limit to the weight of an engine with a given driving power, and it may be fairly assumed that this limit is nearly reached in the motors now in use.

We have pointed out the direction in which improvement may be possible. But, when we consider the resistance of the air, not only do we find the field open to improvement to be limited, but there is one great problem belonging wholly to the future, that of transporting the passenger in safety and comfort upon a machine that can be made available at will. Let us look more closely at the actual conditions. Owing to the levity of the air, the supporting surface must have a wide area. We cannot set any exact limit to the necessary spread of sail, because the higher the speed the less the spread required. But, as we increase the speed, we also increase the resistance, and therefore we must have a more powerful and necessarily heavier motor. Unless the adjustment of parts in Farman's machine is far from perfect, more than a thousand square feet of ground is necessary to hold the flyer when at rest. If the traveller is to possess his own machine, the reader who reflects upon the situation and upon the probable cost, can form as good an idea as any one of the expense involved merely in the storage and care of the flyer. But let us grant that he is so fortunate that cost need not be considered. Then he will certainly need comfort in travel. But, if he attempts to protect himself from the inclemency of the weather and the discomfort of a motion through the air at a speed approaching that of a railway train, we may well doubt whether any person will ever prefer flying to railway travel. There can be no warming of the air without much additional weight, and no protection from the wind without much additional resistance. The highest measure of success which even the idealist could hopefully conceive would place the passenger in much the same condition as regards surroundings as that of a traveller by rail, mounted on a platform without sides or covering, driven along at railroad speed in every sort of weather.

If the machine is to be in charge of a skilful driver, which seems to be essential, it must carry him as well as the passenger. But in this case there is, as I have already pointed out, no way of reaching the result except by so constructing the machine that it shall be equivalent to two flyers, each capable of carrying a man. Then the size of the vehicle, and the general difficulty of management, are all increased in the same proportion. If this view seems pessimistic, if it seems to belong to that large class of predictions which have been belied by the result, I think it can only be from want of full consideration of the obstacles I have pointed out, and from our neglecting to take account of all the conditions. Bearing in mind that no limit is to be set to the possible discovery of new laws of nature or new combinations of the chemical elements, it must be understood that I disclaim any positive prediction that men will never fly from place to place at will. The claim I make is that they will not do this until some epoch-making discovery is made of which we have now no conception, and that mere invention has nearly reached its limit. It is very natural to reason that men have done hundreds of things which formerly seemed impossible, and therefore they may fly. But for every one thing seemingly impossible that they have succeeded in doing there are ten which they would like to do but which no one believes that they can do. No one thinks of controlling wind or weather, of making the sun shine when we please, of building a railroad across the Atlantic, of changing the ocean level to suit the purposes of commerce, of building bridges of greater extent than engineers tell us is possible with the strength of the material that we have at command, or of erecting buildings so high that they would be crushed by their own weight. Why are we hopeless as to all these achievements, and yet hopeful that the flying-machine may be the vehicle of the future, which shall transport us more rapidly than a railroad train now does? It is simply because we all have so clear a mental view of the obstacles in the way of reaching such ends as those just enumerated that we do not waste time in attempting to surmount them, and we are hopeful of the flying-machine only because we do not clearly see that the difficulties are of the same nature as those we should encounter in erecting a structure which would not be subject to the laws of mechanics.

I have said nothing of the possible success of the flying-machine for the purposes of military reconnaissance or any other operations requiring the observer to command a wide view of all that is on the landscape. This is a technical subject which, how great soever may be its national importance, does not affect our daily life. It is, therefore, one in which we can wait patiently to see what success attends the effort made by our Army Signal Office to command a practical flyer. The complex questions arising may well be left to military men, as may all questions relating to the practicability of the dirigible balloon as an engine of warfare. What immediately interests the public is the possibility of the commercial success of aërial flight as a means of travelling with greater speed or greater economy than we now do. The writer cannot see how any one who carefully weighs all that he has said can avoid the conclusion that the era when we shall take the flyer as we now take the train belongs to dreamland.

SIMON NEWCOMB.